C. Kendall Lister

Cahill

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THE MOUNTAIN PINE BEETLE IN LODGEPOLE PINE
Dendroctonus monticolae Hopk.
(Coleoptera:Scolytidae)

PROGRESS REPORT - STUDY I

Development of Sampling Procedures

By

Walter E. Cole
Entomologist

1965

Prepared by

DIVISION OF FOREST INSECT RESEARCH
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Joseph F. Pechanec, Director
Forest Service
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SUMMARY

1. Three sample sizes were compared: (1) 6- x 6-inch, (2) 6- x 12-inch, and (3) "actual" for measurements of attack density and inches of gallery. The 6- x 12-inch sample doubled as the actual sample for the attack density variable, but for the inches of egg gallery measurements the absolute sample was the total length of all completed galleries originating from the 6- x 12-inch sample, even though they terminated outside of the sample. Comparisons showed that reliable estimates of these two variables can be made from the 6- x 6-inch sample.

2. No correlation existed for the comparisons:

   a. Mountain pine beetle vs. parasite-predators.

   b. Secondary hosts vs. parasite-predators.

   c. Mountain pine beetle plus secondaries vs. parasite-predators.

3. Significant differences occurred between plots for both mountain pine beetle and parasite-predator populations. No differences by height in tree was shown when these populations were combined, or within each population. Differences occurred within the parasite-predator population between plots and between insect orders, but uniform distribution occurred by order within trees.

4. Frequency distributions were computed by diameter class and time of sampling. Fall brood data fit a normal distribution; April through July brood data fit a Poisson distribution; and adult emergence data fit a negative bionomical distribution. Five distributions were tested for fit.

5. Sequential sampling plans were developed for brood sampling for all stages except adults at emergence.

INTRODUCTION

Intensive studies on population dynamics of the mountain pine beetle, Dendroctonus monticolae, Hopk., in lodgepole pine were begun in 1961. This study is restricted to the mechanics and statistics of sampling methods for the mountain pine beetle.

The primary objective is to develop reliable methods of measurement and analysis of populations of mountain pine beetle, its biotic agents and environmental influences. A sampling technique for mature larval and pupal stages of the beetle was developed in the generation year 1961-62 (Carlson and Cole 1964). The technique was used in the generation year 1962-63 and proved successful for obtaining the results reported in this paper.

A third study plot was added this past season--Della Basin, Caribou National Forest, Idaho. This plot is located within a new, rapidly developing infestation. In this the second year of increase of the infestation, populations were quite high. The infestation began in 1961 as small groups (less than 10 trees per group) of infested trees and, in the fall of 1963, had increased to groups of 50 and more infested trees.

OBJECTIVES

There were four objectives for the study during the generation year 1962-1963. They were:

1. To compare the 6" x 6" and the 6" x 12" sample sizes for efficiency in measuring attack density and gallery lengths.

2. To test correlation between parasite-predator populations and mountain pine beetle populations.

3. To determine the statistical distribution of the population samples at different times during insect development.

4. To develop sequential sampling plans for sampling at different times during insect development.

RESULTS

1. The sampling technique developed in 1961-1962 was based on brood data, even though both attack density and egg gallery length data were recorded. In the past, brood data was recorded from 6- x 6-inch samples; attack density and egg gallery length were recorded from 6- x 12-inch samples. It would decrease time and ease sampling if these three variables could be measured without loss of reliability from the same sample size. Also, comparisons of the three variables could be handled much easier.

Two sample loci were randomly selected within a subpopulation zone per tree (Carlson and Cole 1964). A 6- x 6-inch bark area was removed first and attack density and gallery length recorded. Next, an adjacent bark area, 6- x 6-inch, was removed vertically up the tree stem producing a 6- x 12-inch bark area. Additional attack and gallery measurements were taken. Lastly, all galleries originating within the 6- x 12-inch area were traced to their completion and measured. This gave the actual population for comparison with the estimates obtained from the 6- x 6-inch and 6- x 12-inch sample sizes. Attack densities were compared only between the two sample sizes--6- x 6-inch and 6- x 12-inch. Attack densities are complete within a sample area whereas gallery lengths can originate within a sample area and terminate outside,

or conversely originate outside and terminate within or originate outside, cross completely through and terminate outside of a sample area. These combinations could distort the estimates obtained by sampling. Hence, the actual measurements of all galleries originating within the sample area for comparison. Number of samples taken by plot were as follows:

Caribou	- 12 trees - 24 samples
Teton	- 23 trees - 46 samples
Lower Wasatch	- 20 trees - 39 samples
Upper Wasatch	- 31 trees - 55 samples

Means, standard deviations, and coefficients of variation were computed by sample size, by plot, for attack density, gallery length, and inches of gallery per attack. These data are shown in the following tables 1, and 2.

All attack density samples showed reasonably small coefficients of variation and small differences between the sample size (table 1).

The 6- x 6-inch sample data, however, did overestimate the 6- x 12-inch sample in the case of attack density. The high variability of the 6- x 6-inch Upper Wasatch sample was probably due to the equalness of frequency between distribution classes and all attack density classes (1 through 8) being represented (fig. 1). This could also be due to the distance of the mean from the modal class. However, in all cases the 6- x 6-inch sample showed a greater tendency toward being normally distributed.

The inches of gallery data showed comparable coefficients of variation to the attack density data. In addition, these coefficients were more closely grouped between areas and sample sizes. Both sample sizes tended to estimate the actual gallery length closer than the sample sizes did for attack density.

Frequency distributions of the data by the three sample sizes were very close to one another also (fig. 2).

Consequently, the 6- x 6-inch sample size is recommended for all three variable measurements: (1) brood density, (2) attack density, and (3) egg gallery lengths.

Table 1.--Means, standard deviation and coefficients of variation for attack density, by plot.

Sample size	6 x 6			6 x 12		
Plot	$\bar{X}$	$S_{\bar{x}}$	C.V.	$\bar{X}$	$S_{\bar{x}}$	C.V.
Caribou	3.88	0.30	7.79	7.50	0.45	6.01
Teton	2.04	0.14	7.01	3.86	0.29	7.48
Lower Wasatch	3.13	0.25	7.88	6.56	0.40	6.10
Upper Wasatch	3.76	0.46	12.23	6.44	0.41	6.37

Table 2.--Means, standard deviation and coefficients of variation for inches of gallery, by plot.

Sample size	6 x 6			6 x 12			Actual		
Plot	$\bar{X}$	$S_{\bar{x}}$	C.V.	$\bar{X}$	$S_{\bar{x}}$	C.V.	$\bar{X}$	$S_{\bar{x}}$	C.V.
Caribou	41.33	3.37	8.16	82.83	6.97	8.42	78.21	6.17	7.88
Teton	17.61	1.18	6.68	34.96	2.30	6.57	34.82	2.71	7.79
Lower Wasatch	30.87	2.06	6.67	66.46	4.94	7.43	60.05	3.77	6.28
Upper Wasatch	28.27	2.17	7.67	54.59	4.09	7.49	50.76	3.83	7.55

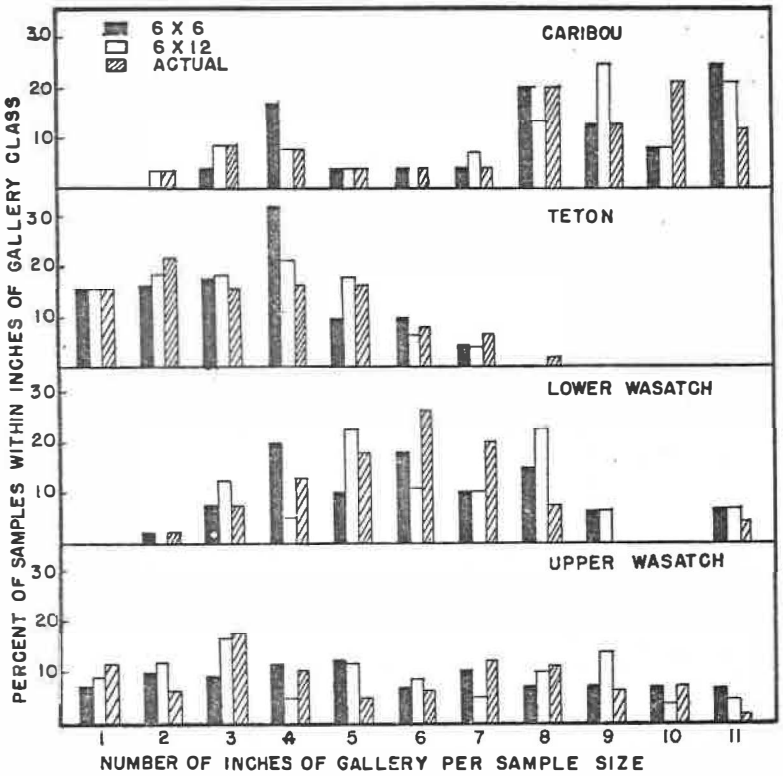

FIGURE 2. Frequency distribution of inches of gallery by 6- X 6-inch, 6- X12-inch and actual sample sizes by plot.

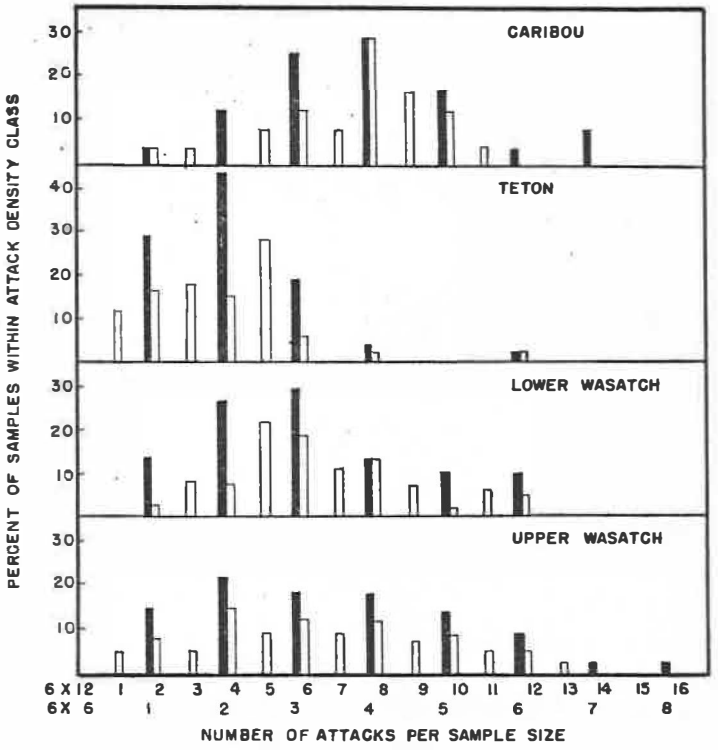

FIGURE 1. Frequency distribution of attack density by 6- X 6-inch and 6- X12-inch samples by plot.

2. Test of correlation between parasite-predator populations and mountain pine beetle populations.

Two comparisons were made: (1) immature stages of both populations and (2) adult stages of both populations. Data for the immature stage comparison were obtained from 10 trees in each of the three plots. Three zones were sampled per tree: breast height, five feet below height of infestation, and midway between these two zones. The stratified random sampling method was used to select 2, 6- x 6-inch samples per zone. All insect forms were recorded by designation at least to family, and in most cases to species.

An analysis of variance of these stratified random samples from both mountain pine beetle and predator-parasite populations, showed differences between plots and, of course, between populations due to the greater number of host insects. No difference occurred by heights for either--both populations combined or each population separately.

Table 3.--Distribution of parasite-predator and host insects population means within and between study plots.

	Areas		
Variable	Wasatch	Teton	Caribou
Both populations	68.71	46.53	47.73

	Populations	
	Hosts	Parasite-predators
All areas	137.92	25.05

	Height		
	DBH	Mid	5' Below
Both populations	51.05	54.35	57.57
(Host)	41.94	46.55	49.43
(P/P)	9.11	7.80	8.14

	Area					
	Wasatch		Teton		Caribou	
Interaction	Host	P/P	Host	P/P	Host	P/P
	57.23	11.48	36.09	10.44	44.60	3.13

The distribution picture remained unchanged when using the parasite-predator population alone and separating it by orders: Coleoptera, Hymenoptera, and Diptera.

Differences occurred between plots and between insect orders, but the distribution of parasite-predator populations within the tree was rather uniform. Not much can be said about the order distribution within the tree and between plots due to the small numbers (table 4). However, when predaceous order populations are combined for areas, and when these predators do occur in numbers, they are usually concentrated in the sample at breast height.

Table 4.--Distribution of parasite-predator population means within and between plots.

	Parasite-Predator		
Variable	Coleoptera	Hymenoptera	Diptera
All areas	14.79	9.00	1.26
	Area		
Interaction	Wasatch	Teton	Caribou
Coleoptera	7.64	4.62	2.53
Hymenoptera	2.88	5.82	0.30
Diptera	0.96	0.00	0.30

The distributions of the two adult populations did not change from the distribution of the immature populations. Correlations were calculated for these associations. Correlations were tested for both brood and adult populations in the following comparisons:

1. Mountain pine beetle vs. parasite-predator
2. Secondary host vs. parasite-predator
3. Mountain pine beetle plus secondaries vs. parasite-predator

No correlation existed for the above comparisons when using sums, variances of the mean ($S^2_{\bar{x}}$) or mean x variance of the mean $\left((\bar{X})(S^2_X) \right)$ for either brood or adult stages.

A multiple regression analysis was computed for the adult populations using mountain pine beetle and secondaries against the three orders of parasites and/or predators. Neither the partial correlation coefficient nor the multiple regression were significant. It is entirely possible that a different sampling scheme will have to be devised to relate these populations, if a relationship does exist.

3. Determination of the statistical distribution of the population samples at different times during insect development.

Frequency distributions were computed from samples taken from four diameter classes: (1) < 9" d.b.h., (2) 10" - 12" d.b.h., (3) 13" - 15" d.b.h., and (4) > 16" d.b.h., for the insect stages: (1) eggs and young larvae (fall), (2) young and mature larvae (April), (3) mature laavae (May), (4) mature larvae and pupae (June), and (5) pupae and callow adults (July).

Distributions by diameter classes were not appreciably different from each other by month. The frequency distributions for combined diameter classes by month of sampling are shown in figure 3. Number of samples taken by month were: Fall - 1,168, April - 419, May - 300, June 89, and July - 119.

Test for normality was made for the fall brood data (Snedecor 1957). Both skewness (g_1) and kurtosis (g_2) were tested; each was small in value, 0.56507 and 0.04206 respectively, and each was positive. Positive g_1 and g_2 values indicate symmetry (mean greater than the median) and lack of kurtosis (flat-topped distribution curves). Both values were close to zero, particularly the g_2 value, and since neither g was significant, there is little evidence of departure from normality in the fall brood population (fig. 4).

The normal, negative binomial, and Poisson distribution for the April through July samples were computed using the relationship between the means and variances. The negative binomial curve did not fit the plotted data and some discrepancies were noted for the Poisson curve and for the relationship between means and variances. Thus, the April data were further tested for different types of statistical distributions: Poisson (Steel and Torrie 1960), truncated Poisson (Cohen 1960) negative bionomial (Bliss) and Neyman's Type A (Douglas 1955). These distributions were fitted to the data from the monthly samples collected as shown in table 5 and figure 5.

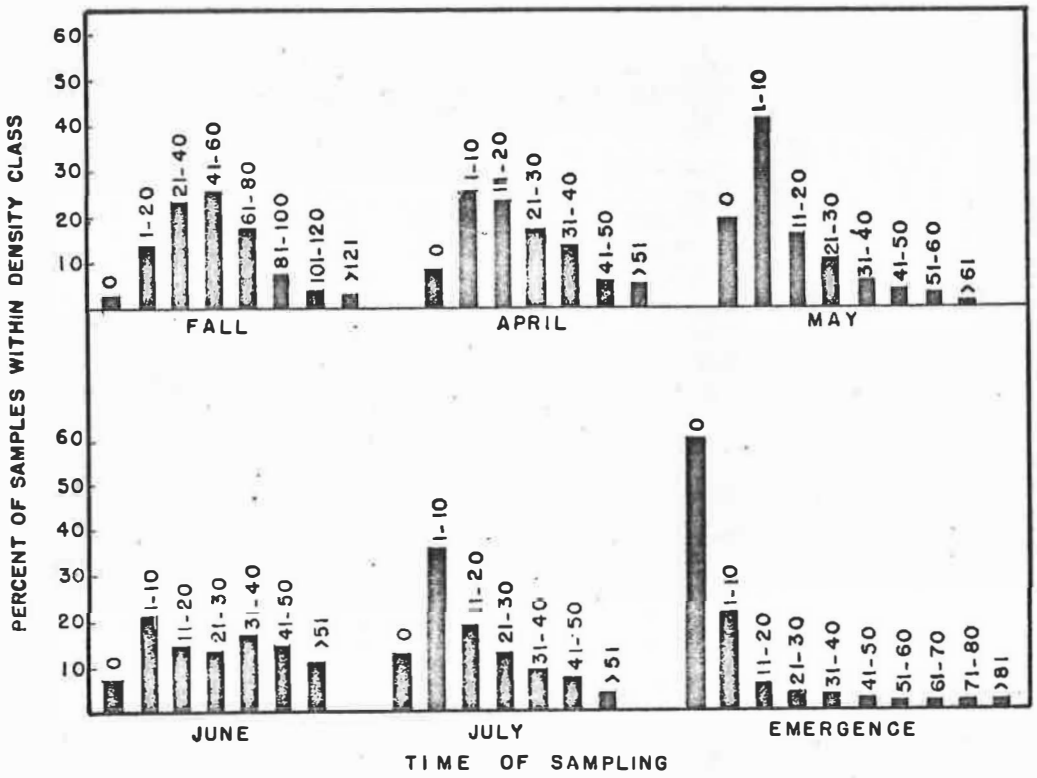

FIGURE 3. Frequency distribution of mountain pine beetle broods for combined diameter classes by month of sampling.

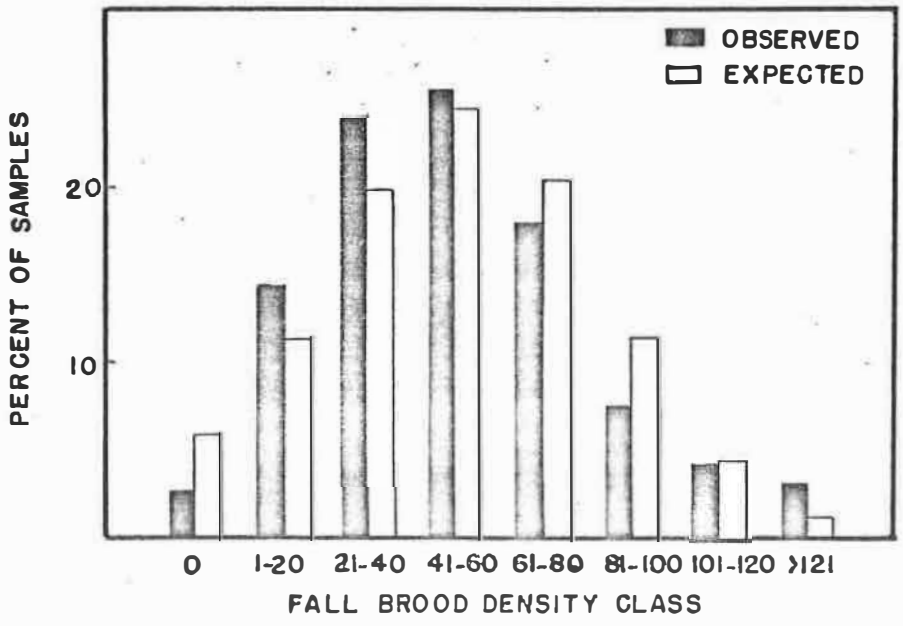

FIGURE 4. Frequency distribution of mountain pine beetle fallbrood; observed and expected for a normal distribution.

Table 5.--Observed distribution and expected frequencies for five different distributions.

Beetles per sample	Observed frequency	Calculated Frequencies: Normal	Poisson	Trunc. Poisson	Negative bionomical	Neyman's A
0	36	7.46	37.21	40.87	52.40	56.41
1-10	106	51.54	94.23	89.19	90.84	70.18
11-20	99	142.00	109.00	108.92	104.58	76.01
21-30	72	148.87	88.23	88.67	89.33	68.60
31-40	57	59.58	53.55	54.14	44.55	55.22
41-50	26	9.05	26.04	26.45	26.06	50.69
> 50	23	0.05	10.61	10.76	11.24	41.89
Sum	419	419.00	419.00	419.00	419.00	419.00

Test for normality showed a highly significant positive g_1 (91.45072) which indicates a highly skewed curved and an extremely small, not significant, positive g_2 (0.005841) which indicates no kurtosis. The χ^2 value was extreme for a normal distribution. The χ^2 values for distributions other than normal (table 6) do not show a good fit either.

Table 6.--Values of χ^2 for various distributions calculated χ^2 for distributions tested.

	Normal	Poisson	Trunc. Poisson	Neg. bio.	Neyman's A
$\chi^2 0.01 = 15.1$ $\chi^2 0.05 = 12.8$	3093.00	22.02	21.85	27.11	53.37

However, it would appear from fig. 5 that the Poisson distribution had the closest fit.

The statistical distribution for the emerging population (adults) was not computed. However, experience has shown that the frequency distribution for this stage (fig. 3) would more than likely be of the negative bionomical distribution.

The practical advantages of computing distributions are for application of a transformation to change the distribution to normalcy in order to utilize existing methods of analyses and to develop a sequential sampling plan. However, the need for computing statistical distributions is seriously doubted in view of recent developments in non-parametric analyses, mainly due to the influence of sample size upon determining the characteristics of the distribution. This influence should possibly receive further investigation.

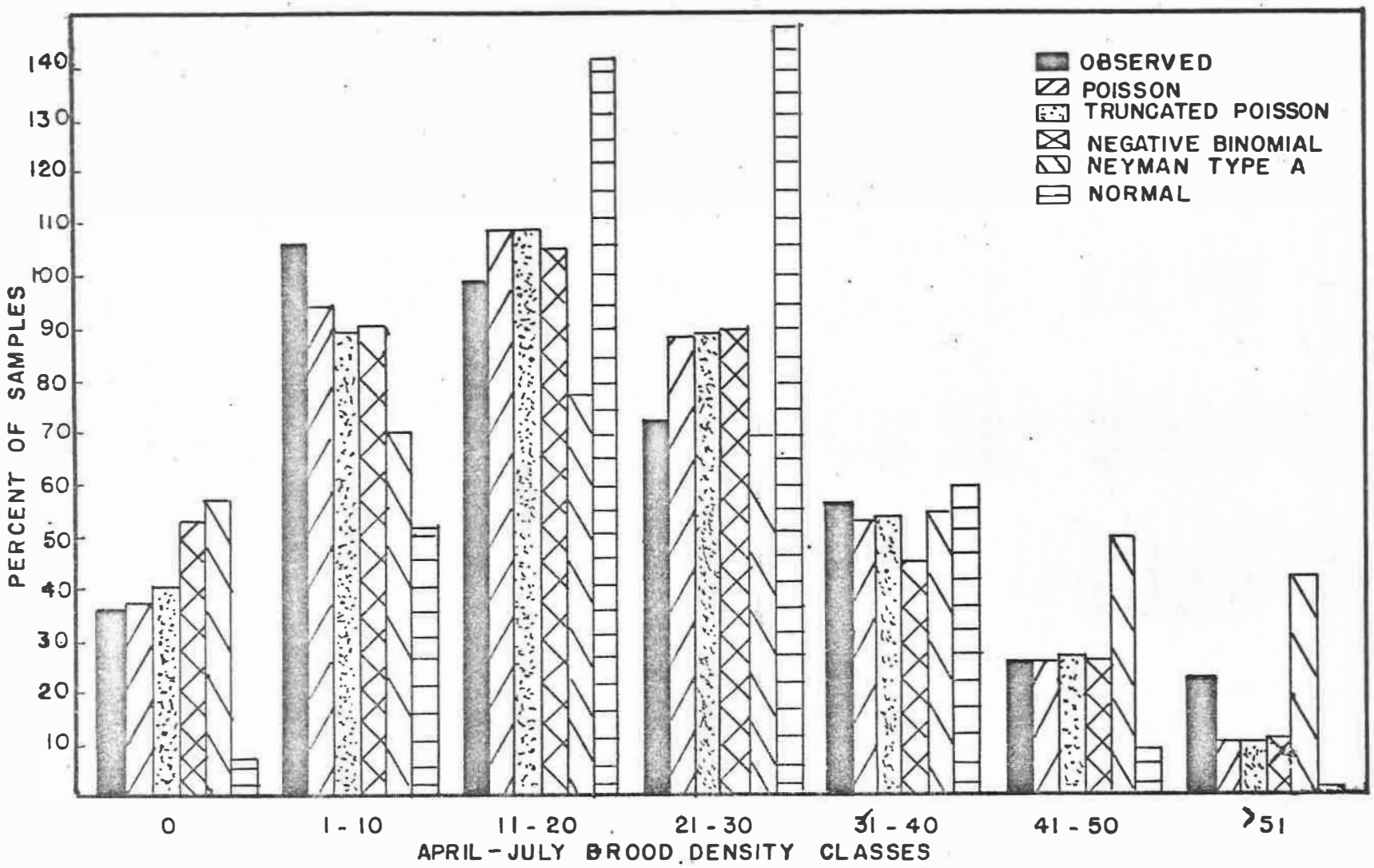

FIGURE 5. Frequency distribution of mountain pine beetle april-july broods; observed and expected for five distributions.

4. Development of sequential sampling plans for sampling at different times during insect development.

Statistical distributions used to compute the following sequential sampling plans were: Fall brood--normal and April through July--Poisson. Sampling emerging adults by use of the sequential plan would present some practical limitations. Consequently, no plan was computed for this stage. Numerous reports on the application of the sequential plan to biological problems have been published. Formulae used for these plans were presented by Oakland (1951).

Sample selection proceeds in the same manner as reported by Carlson and Cole (1964). Two 6- x 6-inch samples from each tree are selected by a stratified random method (page 2).

Two kinds of errors are involved - Type I (α), and Type II (β). Risk α is the probability of rejecting a null hypothesis when it is in fact true and risk β the probability of accepting it when it is not true. Generally, odds of 1:10 are more than acceptable for forest insect evaluations. Thus, α and β for time of sampling April-July were set at 0.10. Due to the normal distribution of the fall brood, α and β can be set at 0.01 or 1:100.

Class limits used in computing each plan are based on life table data obtained from the population study between 1961-1963. The zone between Decision 1 and Decision 2 should express a continuing epidemic.

Fall - Decision 1--Lower limit: 40 or less beetles per 6- x 6-inch sample
--Upper limit: 43 or more beetles per 6- x 6-inch sample

Decision 2--Lower limit: 47 or less beetles per 6- x 6-inch sample
--Upper limit: 50 or more beetles per 6- x 6-inch sample

April - Decision 1--Lower limit: 10 or less beetles per 6- x 6-inch sample
--Upper limit: 16 or more beetles per 6- x 6-inch sample

Decision 2--Lower limit: 20 or less beetles per 6- x 6-inch sample
--Upper limit: 26 or more beetles per 6- x 6-inch sample

May - Decision 1-- Lower limit: 6 or less beetles per 6- x 6-inch sample
--Upper limit: 10 or more beetles per 6- x 6-inch sample

May - Decision 2--Lower limit: 13 or less beetles per 6- x 6-inch sample
--Upper limit: 16 or more beetles per 6- x 6-inch sample

June - Decision 1--Lower limit: 4 or less beetles per 6- x 6-inch sample
--Upper limit: 6 or more beetles per 6- x 6-inch sample

Decision 2--Lower limit: 8 or less beetles per 6- x 6-inch sample
--Upper limit: 10 or more beetles per 6- x 6-inch sample

July - Decision 1--Lower limit: 1 or less beetles per 6- x 6-inch sample
--Upper limit: 2 or more beetles per 6- x 6-inch sample

Decision 2--Lower limit: 4 or less beetles per 6- x 6-inch sample
--Upper limit: 5 or more beetles per 6- x 6-inch sample

These limits between Decisions 1 and 2 should produce a 1:1 trend of attacks. Knowledge of attack density in relation to epidemic has not been refined to give definite standards--rather this work indicates trend. True, in life table studies, the "when" of reduction is as important or more so than the "how much." However, use of these sequential plans will reveal the occurrence and magnitude of critical changes in a life table.

The acceptance and rejection lines for each plan are as follows:

1. Fall (normal distribution):

$\alpha_1 = \beta_1 = \alpha_2 = \beta_2 = 0.01$

$a_1 = a_2 = \frac{\ln 1 - \beta}{\alpha} = 4.595$

$b_1 = b_2 = \frac{\ln 1 - \alpha}{\beta} = 4.595$

m_1 = smaller (accept) average = 40 per 1/4 sq. ft.

m_2 = larger (reject) average = 43 per 1/4 sq. ft.

m_3 = smaller (accept) average = 47 per 1/4 sq. ft.

m_4 = larger (reject) average = 50 per 1/4 sq. ft.

h_1, h_2, h_3, and h_4 are the intercepts

with the ΣX (sum of X's for an observation in a sample)

axis on the graph and are equal to:

$$h_1 = \frac{-b_1 \sigma^2}{m_2 - m_1} = h_2 = \frac{a_1 \sigma^2}{m_2 - m_1} = \pm 3.75$$

$$h_3 = \frac{b_2 \sigma^2}{m_2 - m_3} = h_4 \frac{a_2 \sigma^2}{m_4 - m_3} = \pm 3.75$$

and the slope of the lines:

$$s_1 = \frac{m_1 + m_2}{2} = 41.5; \quad s_2 = \frac{m_3 + m_4}{2} = 48.5$$

The lines are: ΣX_1 & $X_2 = 41.5\ n \pm 3.75$; $(h_1$ & $h_2)$

ΣX_3 & $X_4 = 48.5\ n \pm 3.75$; $(h_3$ & $h_4)$

The average size samples to be taken were computed from the following formula:

$$\bar{n}_{m_1} = \frac{(1 - \alpha_1) - \alpha_1 a_1}{\frac{(m_2 - m_1)^2}{2\sigma^2}} = 2.45$$

$$\bar{n}_{m_2} = \frac{(1 - \beta_1) a_1 - \beta_1 b_1}{\frac{(m_2 - m_1)^2}{2\sigma^2}} = 2.45$$

In this case $\bar{n}_{m_1} = \bar{n}_{m_2} = \bar{n}_{m_3} = \bar{n}_{m_4}$

The sequential plan for sampling mountain pine beetle fall broods is shown in figure 6 and table 7, followed by similar information for April broods in figure 7 and table 8.

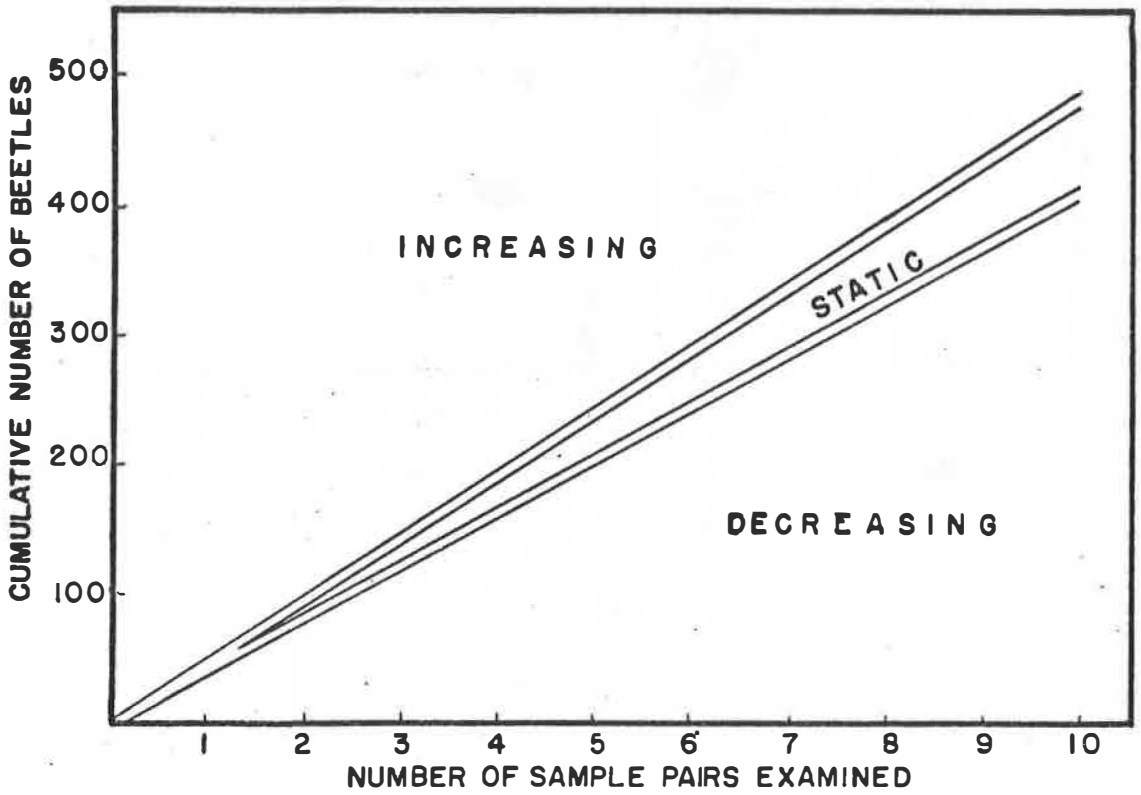

FIGURE 6. Sequential graph for sampling mountain pine beetle fall broods.

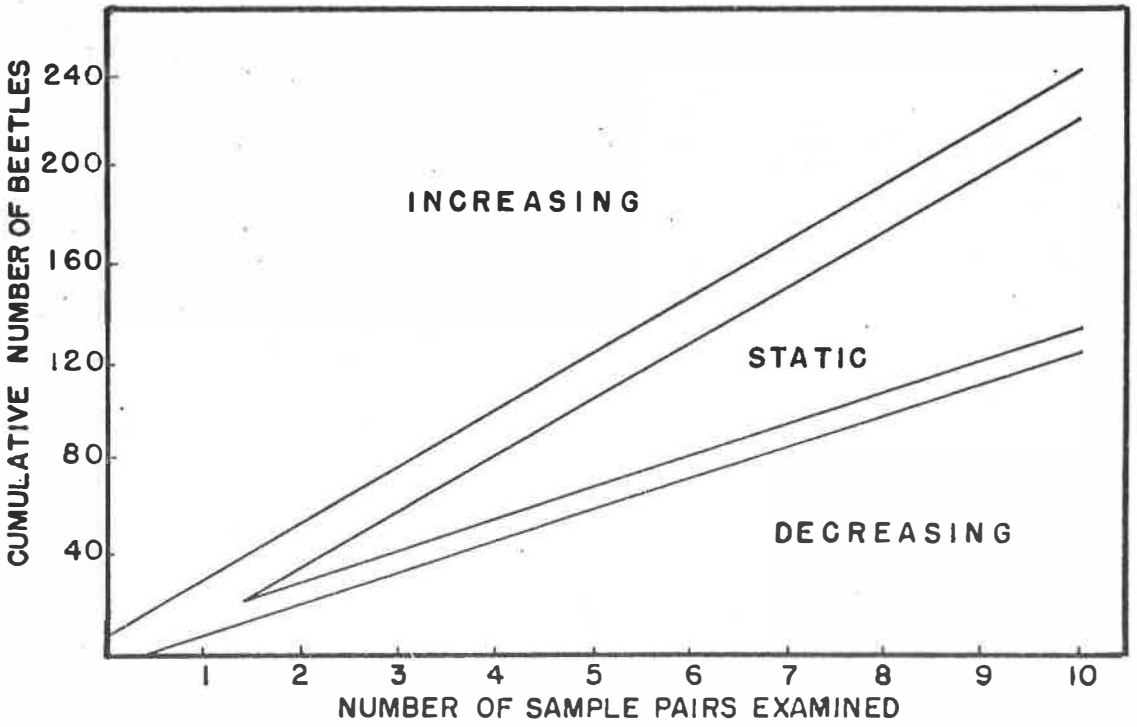

FIGURE 7. Sequential graph for sampling mountain pine beetle April broods.

Table 7.--Sequential table for sampling mountain pine beetle fall broods from a 6- x 6-inch sample.

Number of samples		Cumulative number of larvae							
		< 40		> 43		< 47		> 50	
1		38		--		--		52	
2		80		87		93		101	
1/ 3		121		128		142		149	
4		163		170		190		198	
5		204		211		239		246	
6		246		253		287		295	
7	decreasing	287	continue sampling	294	epidemic	336	continue sampling	343	increasing
8		329		336		384		392	
9		370		377		433		440	
10		412		419		481		489	

1/ Average sample needed.

2. April (Poisson distribution):

$\alpha_1 = \beta_1 = \alpha_2 = \beta_2 = 0.10$

$a_1 = a_2 = \frac{\ln \frac{1-\beta}{\alpha}}{} = 12.766$

$b_1 = b_2 = \frac{\ln \frac{1-\alpha}{\beta}}{} = 12.766$

$m_1 = 10$; $m_2 = 16$: $m_3 = 20$; $m_4 = 26$

$h_1 = \frac{b}{\ln \frac{m_2}{m_1}} = h_2 = \frac{a}{\ln \frac{m_2}{m_1}} = \pm 4.67493$

$h_3 = \frac{b}{\ln \frac{m_2}{m_1}} = h_4 = \frac{a}{\ln \frac{m_2}{m_1}} = \pm 8.37450$

And the slope of the lines:

$s_1 = \frac{m_2 - m_1}{\ln \frac{m_2}{m_1}} = 12.76595$; $s_2 = 22.86846$

The lines are:

$\Sigma X_{1\&2} = 12.76595\ n \pm 4.67493$; $(h_1 \& h_2)$

$\Sigma X_{3\&4} = 22.86846\ n \pm 8.37450$; $(h_3 \& h_4)$

The average size samples to be taken were computed from the following formulae:

$$\bar{n}_{m_1} = \frac{(1 - \alpha) - \alpha a}{(m_2 - m_1) - m_1 \ln \frac{m_2}{m_1}} = 1.35$$

$$\bar{n}_{m_2} = \frac{(1 - \beta)\, a - \beta b}{m_2 \ln \frac{m_2}{m_1} - (m_2 - m_1)} = 1.16$$

and $\bar{n}_{m_3} = 2.33$; $\bar{n}_{m_4} = 2.14$

Table 8.--Sequential table for sampling mountain pine beetle April broods from a 6- x 6-inch sample.

Number of samples	Cumulative number of larvae					
	< 10		> 16	< 20		> 26
1	8		---	---		31
1/ 2	21		30	37		54
3	34		43	60		77
4	46		56	83		100
5	59	continue sampling	69	106	continue sampling	123
6	72		81	129		146
7	85		94	152		168
8	97		107	175		191
9	110		110	197		214
10	123		132	220		237

1/ Average sample needed.

3. May (Poisson Distribution):

The formulae for the sequential plan for the Poisson distribution have been stated. The risks α and β have been set at 0.10 for April through July, thus many figures involving this figure will remain constant for these times of sampling. Only pertinent formulae and figures will be stated hereafter.

$$\alpha_1 = \beta_1 = \alpha_2 = \beta_2 = 0.10$$

$$a_1 = b_1 = a_2 = b_2 = 2.19722$$

$$m_1 = 6;\ m_2 = 10;\ m_3 = 13;\ m_4 = 16$$

$$h_1 = h_2 = \pm 4.30127;\ s_1 = 7.83039$$

$$h_3 = h_4 = \pm 10.58157;\ s_2 = 14.44808$$

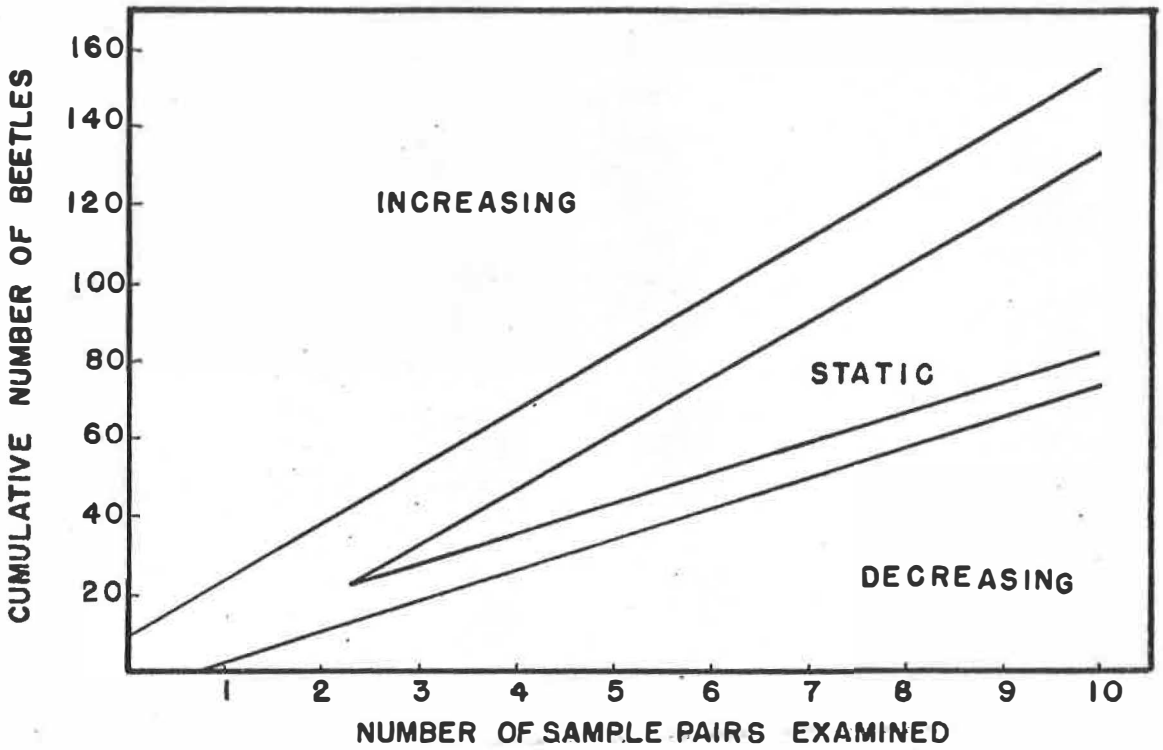

FIGURE 8, Sequential graph for sampling mountain pine beetle May broods.

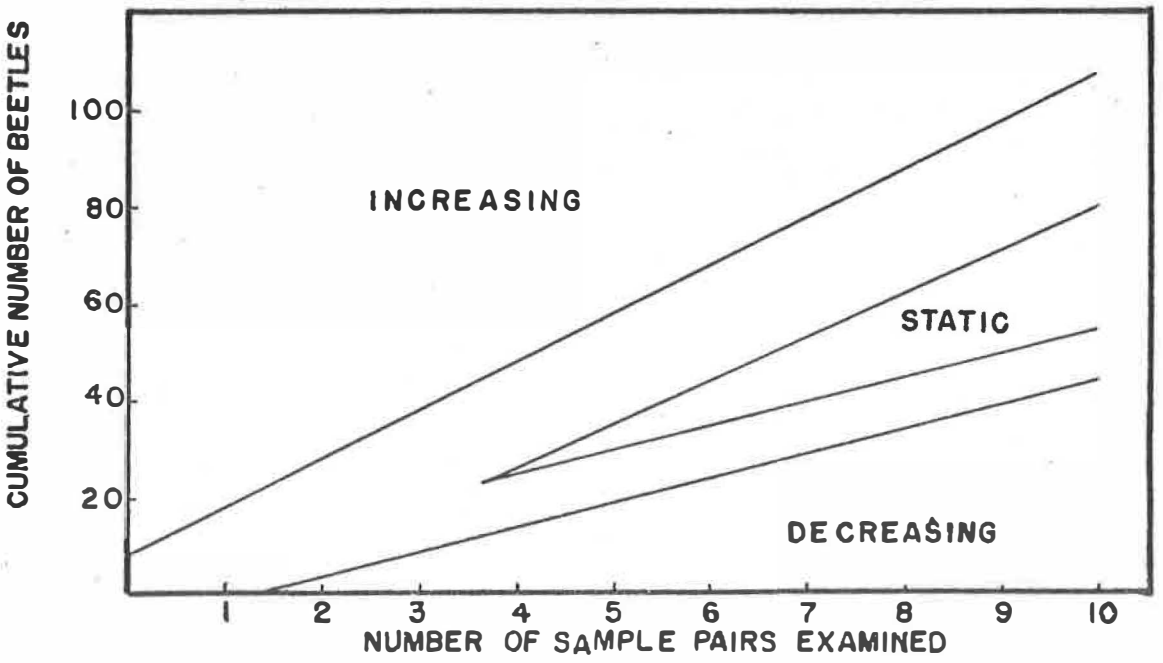

FIGURE 9. Sequential graph for sampling mountain pine beetle June broods.

The lines are: $\Sigma X_{1 \& 2} = 7.83039\ n \pm 4.30127$; ($h_1$ & h_2)

$\Sigma X_{3 \& 4} = 14.44808\ n \pm 10.58157$ (h_3 & h_4)

The average samples to be taken are:

$\bar{n}_{m_1} = 1.90$; $\bar{n}_{m_2} = 1.56$

$\bar{n}_{m_3} = 5.69$; $\bar{n}_{m_4} = 5.63$

Table 9.--Sequential table for sampling mountain pine beetle May broods from a 6- x 6-inch sample.

Number of samples	Cumulative number of larvae			
	< 6	> 10	< 13	> 16
1	4	--	--	25
2	11	--	--	39
3	19	28	33	54
4	27	36	47	68
5	35	43	62	83
6	43	51	76	97
7	51	59	91	112
8	58	67	105	126
9	66	75	119	141
10	74	83	134	155

continue sampling

continue sampling

4. June (Poisson Distribution):

$\alpha_1 = \beta_1 = \alpha_2 = \beta_2 = 0.10$

$a_1 = b_1 = a_2 = b_2 = 2.19722$

$m_1 = 4$; $m_2 = 6$; $m_3 = 8$; $m_4 = 10$

$h_1 = h_2 = \pm 5.41894$; $s_1 = 4.93254$

$h_3 = h_4 = \pm 9.84638$; $s_2 = 8.96258$

The lines are:

$\Sigma X_{1\ \&\ 2} = 4.93254\ n \pm 5.41894$; ($h_1$ & h_2)

$\Sigma X_{3\ \&\ 4} = 8.96258\ n \pm 9.84638$; ($h_3$ & h_4)

The average samples to be taken are:

$\bar{n}_{m_1} = 4.65$; $\bar{n}_{m_2} = 4.06$

$\bar{n}_{m_3} = 8.18$; $\bar{n}_{m_4} = 7.60$

Table 10.--Sequential table for sampling mountain pine beetle June broods from a 6- x 6-inch sample.

Number of samples	Cumulative number of larvae							
	< 4		> 6		< 8		> 10	
1	--		--		--		19	
2	4		--		--		29	
3	9		--		--		39	
4	14	continue sampling	25		26	continue sampling	48	
1/ 5	19		30		35		58	
6	24		35		44		68	
7	29		40		53		78	
8	34		45		62		88	
9	39		50		71		98	
10	44		55		80		107	

1/ Average sample needed

5. July (Poisson Distribution):

$\alpha_1 = \beta_1 = \alpha_2 = \beta_2 = 0.10$

$a_1 = b_1 = a_2 = b_2 = 2.19722$

$m_1 = 1;\ m_2 = 2;\ m_3 = 4;\ m_4 = 5$

$h_1 = h_2 = \pm\ 3.16990;\ s_1 = 1.44268$

$h_3 = h_4 = \pm\ 9.84638;\ s_2 = 4.48129$

The lines are:

$\Sigma X_{1\ \&\ 2} = 1.44268\ n \pm 3.16990;\ (h_1\ \&\ h_2)$

$\Sigma X_{3\ \&\ 4} = 4.48129\ n \pm 9.84638;\ (h_3\ \&\ h_4)$

The average samples needed are:

$\bar{n}_{m_1} = 5.73;\ \bar{n}_{m_2} = 4.55$

$\bar{n}_{m_3} = 16.36;\ \bar{n}_{m_4} = 15.19$

Table 11.--Sequential table for sampling mountain pine beetle July broods from 6- x 6-inch sample.

Number of samples	Cumulative number of larvae			
	< 1	> 2	< 4	> 5
1	--	--	--	14
2	--	--	--	19
3	1	--	--	23
4	3	--	--	28
5	4	10	13	32
1/ 6	5	12	17	37
7	7	13	22	41
8	8	15	26	46
9	10	16	30	50
10	11	18	35	55
11	12	19	39	59
12	14	21	44	64
13	15	22	48	68
14	17	24	53	73
15	18	25	57	77
16	20	27	62	82
17	21	28	66	86

continue sampling

continue sampling

1/ Average sample needed

The use of sequential sampling should be quite familiar to most insect evaluators. The only difference in use of these sequential plans and others is the averaging of the two random stratified samples per tree to obtain the number of live brood for the cumulation of sums. In other words, the average samples needed is the number of trees; two random stratified samples per tree, averaged.